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Production and Nutritive Value of Grazed Simple and Complex Forage Mixtures

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ABSTRACT

Sustainability of forage production in the Northeast USA is affected by environmental and climatic variability. Complex forage mixtures may be better adapted than simple mixtures to variable environments and produce greater dry matter (DM) yield more evenly throughout the growing season, thereby increasing sustainability of forage production. A grazing trial was set up to evaluate forage production, nutritive value, and botanical composition dynamics of well-adapted and commonly sown forage species. The forage treatments consisted of simple mixtures (two and three species) and complex mixtures (six and nine species). The experiment was mob-grazed with cow–calf (*Bos taurus* L.) pairs five times each year. Dry matter distribution during the growing season was independent of mixture complexity; it was, instead, influenced mainly by the weather. When averaged across all 3 yr, mixtures containing six species produced greater ($P < 0.001$) forage yield (9900 kg DM ha^{-1}) compared with two-species (8700 kg DM ha^{-1}) or three-species mixtures (8400 kg DM ha^{-1}). However, forage production varied within species richness groups. In general, regardless of the initial botanical composition, the predominant species in most mixtures by the end of the experiment were orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb.), and white clover (*Trifolium repens* L.). Variation in nutritive value among mixtures was explained mainly by variation in the proportions of grasses and legumes. We conclude that when it comes to large yields and top nutritive value, the most important consideration is the individual species, not the complexity of the mixtures.

Sustained forage production on pastures depends on a complex meld of soil, weather, topography, and the changes brought about by the grazing animals themselves. Complex topography and varied soil types create microsites that allow the growth of varied botanical communities (Belesky et al., 2002a; Tilman, 2001). Production is affected by variability of soils and unpredictable weather that dominate cool-temperate regions (Belesky et al., 1999). Grazing livestock adds another level of complexity through selective grazing and their uneven return of nutrients, which leads to increased-fertility patches (Belesky et al., 2002b).

Research in natural ecosystems has shown that environments with broader plant diversity tend to provide increased and more consistent community biomass (Tilman, 2001). Thus, increasing the floristic diversity of forage mixtures could improve resource utilization (nutrient, light, and space) and rapidly adjust to climatic changes (Belesky et al., 2002b; McKenzie et al., 1999; Tilman 1999). Such an advantage would be realized only if the components of the mixtures were sufficiently varied to fully exploit the environment (Ingram, 1997). Complex mixtures are thought to be better adapted to marginal environments if the mixtures are composed of a relatively large number of well-adapted species (Annicchiarico et al., 1995).

Complex mixtures composed of species with marked differences in seasonal growth pattern may provide greater yields than simpler mixtures. The sequence of each species peak production during the growing season may spread forage production throughout the growing season and may increase total forage production (Piano and Annicchiarico, 1995; Belesky et al., 2002b). Consequently, complex mixtures would be advantageous due to the achievement of some degree of sustainable production (Belesky et al., 1999; Crosthwaite et al., 1996).

The botanical composition of complex mixtures changes with time and is influenced mainly by the environment and grazing management (Belesky et al., 2002b, 2002a, respectively). Botanical shifts may influence forage nutritive value and make complex mixtures more difficult to manage (Crosthwaite et al., 1996; Sleugh et al., 2000; Wilson and Clark, 1960; Belesky et al., 1999). In simple grass–legume mixtures it was found that the grass-to-legume proportion strongly influenced crude protein (CP) and neutral detergent fiber (NDF) (Sheaffer et al., 1990; Zemenchik et al., 2002). White et al. (2004), working on native grasslands in New Zealand, concluded that increasing plant species diversity was associated with smaller CP, in vitro true dry matter digestibility (IVTDMD), and greater NDF concentrations.

The effect of increased species richness on DM production is controversial. On the one hand, research in clipped plots has shown that complex mixtures of temperate forage species did not produce greater yields than the best-yielding pure grass stand (Piano and Annicchiarico, 1995; Annicchiarico et al., 1995). The agronomic advantage of complex forage mixtures for total DM yield may be limited (Zannone et al., 1983). On the other hand, recent dairy grazing research in the Northeast USA concluded that sowing moderately complex mixtures (three to six species) would increase forage production (Sanderson et al., 2005).

The objective of this study was to test the hypothesis that complex mixtures (six and nine species) are more productive and of better nutritive value than simple mixtures (two and three species) under grazing. We analyzed DM yield, nutritive value, and botanical composition dynamics as described in the following section.

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Abbreviations: CP, crude protein; DM, dry matter; IVTDMD, in vitro true dry matter digestibility; NDF, neutral detergent fiber.

MATERIALS AND METHODS

Thirteen forage mixtures were seeded into tilled 3- by 5-m plots on 15 Aug. 2001 at the Pennsylvania State University Haller Farm, State College, PA (40°51′ N, 77°51′ W, 350 m above sea level; Table 1). Producers in the northeast USA plant a range of forage mixtures from two to nine species of cool-season grasses and legumes along with chicory (*Cichorium intybus* L.) (Sanderson, 2005). The mixtures we compared were representative of those used by producers. 'Tekapo' orchardgrass, 'Bronson' tall fescue, 'Tonga' perennial ryegrass (*Lolium perenne* L.), 'Common' Kentucky bluegrass (*Poa pratensis* L.), 'Winter' alfalfa (*Medicago sativa* subsp. *sativa*), 'Starfire' red clover (*Trifolium pratense* L.), 'Jumbo' white clover, 'Viking' birdsfoot trefoil (*Lotus corniculatus* L.), and 'Puna' chicory were used in the mixtures (Table 1). The nine species used in this study are among the most commonly planted species in forage mixtures according to our surveys (Sanderson, 2005).

The design of the experiment was a randomized complete block with four replicates. Seeding density was 1000 live seeds m^{-2}. Soil tests performed the previous spring (April 2001) indicated a pH of 6.9, 63 kg ha^{-1} of available P, and 220 kg ha^{-1} of available K in the surface 15 cm. Therefore, plots were fertilized in October 2001 with 30 kg P and 187 kg K ha^{-1}. No inorganic N was applied during the trial. Data were collected during the 2002, 2003, and 2004 grazing seasons.

The plots were mob-grazed five times per growing season (Table 2) as follows. When the sward height of the mixtures reached an average height of 25 cm, 12 to 14 cow–calf pairs of mixed breeds were released onto the land containing the plots and allowed to remain until the sward height was reduced to an average of 7.5 cm, which took from 8 to 12 h. Average stocking density was 34 500 kg live wt ha^{-1}. After grazing, the dung was manually removed from the plots and the stubble mowed so that none of it stood taller than 7.5 cm.

Table 1. Seeding ratio of forage mixtures established at the Haller Farm near State College, PA, to determine the effect of such mixtures on forage production and herbage quality of the subsequent pasture, August 2001.

Mixture	Species percentage in each mixture
	Two-species mixtures
1†	65% orchardgrass–35% alfalfa
2†	65% Kentucky bluegrass–35% white clover
3†	65% tall fescue–35% red clover
4†	65% perennial ryegrass–35% white clover
5†	50% chicory–50% red clover
	Three-species mixtures
6‡	50% orchardgrass–30% alfalfa–20% chicory
7‡	50% perennial ryegrass–30% white clover–20% chicory
8†	30% tall fescue–30% Kentucky bluegrass–40% birdsfoot trefoil
9†	50% orchardgrass–25% red clover–25% white clover
	Six-species mixtures
10§	20% orchardgrass–20% tall fescue–30% perennial ryegrass–14% Kentucky bluegrass–12% red clover–4% white clover
11¶	36% orchardgrass–36% perennial ryegrass–10% Kentucky bluegrass–4% white clover–8% birdsfoot trefoil–6% chicory
12#	25% orchardgrass–25% tall fescue–10% alfalfa–10% red clover–20% birdsfoot trefoil–10% chicory
	Nine-species mixture
13	11% orchardgrass–11% tall fescue–11% perennial ryegrass–11% Kentucky bluegrass–11% alfalfa–11% red clover–11% white clover–11% birdsfoot trefoil–11% chicory

† Combinations of grasses and legumes often used in the northeast, with the exception of the chicory–red clover mixture (Sanderson, 2005).
‡ Grass–legume check with a forb (chicory).
§ Commercially available "Highland mix," AMPAC seed company, Tangent, OR.
¶ Commercially available "Intensive grazing mix," AMPAC seed company, Tangent, OR.
# Designed to have higher legume content than Mixtures 10 and 11.

Table 2. Grazing dates for the forage mixtures during 2002, 2003, and 2004 at the Haller Farm near State College, PA.

Year	Spring	Summer	Fall
2002	29 Apr., 3 May	1 July, 12 Aug.	11 Nov.
2003	19 May, 23 June	21 July, 20 Aug.	30 Sept.
2004	17 May, 21 June	21 July, 15 Aug.	15 Sept.

To estimate herbage mass, each plot was divided in thirds lengthwise. Within each third, a random sample of 0.1-m^2 quadrat was clipped to a stubble height of 7.5 cm no more than 1 h before the cattle were released to graze the plots. The three samples of each plot were combined and dried at 60°C for 48 h. All grazings before 15 June were totaled as spring yield, all grazings between 16 June and 31 August were totaled as summer yield, and all grazings after 1 September were totaled as fall yield. Botanical composition was determined for the first, third, and fifth harvests of each growing season by hand sorting the clipped samples by species before drying.

Nutritive value was determined on hand-clipped samples from each harvest in 2002 and 2003. Samples were ground to pass a 2-mm screen in a Wiley mill (Thomas-Wiley, Philadelphia, PA). Crude protein, fiber fractions, and digestibility were determined by near infrared reflectance spectroscopy (Model 6250, NIRSystems, Silver Springs, MD). A validation set of 20 samples was selected with WinISI II software (Infra Soft International, Port Matilda, PA) and used to test the validation equation. The same validation set of 20 samples was analyzed for CP (CP = combustion N × 6.25; Association of Official Analytical Chemists, 1990), NDF, acid detergent fiber, and IVTDMD. Calibration statistics are presented in Table 3.

Forage nutritive value data were averaged for each mixture and for each year weighted by DM yield. The weighted average for nutritive value measures for each mixture was calculated as

$$\mathrm{WACP} = (\Sigma \mathrm{CP}_i \times \mathrm{DM}_i)/\Sigma \mathrm{DM}_i$$

where WACP represents the weighted average of CP (g kg^{-1} DM), CP_i represents the CP content (g kg^{-1} DM) of harvest i, and DM_i represents the DM of harvest i.

Dry matter yield, botanical composition, and weighted average forage nutritive value data were analyzed with the PROC MIXED procedure of SAS (SAS Institute, 1999). The model for DM yield and weighted average forage nutritive value included the fixed effects of species richness, mixtures nested within species richness, years, and species richness by year. In addition, the model included the random effect of replicates, and was analyzed as repeated across years.

The model for botanical composition included the fixed effects of species richness, harvest sequence, and species richness by harvest sequence. In addition, the model included the

Table 3. Calibration statistics for forage nutritive value estimated by near infrared reflectance spectroscopy. Calibration statistics were used for data collected from the forage mixtures during 2002 and 2003 at the Haller Farm near State College, PA.†

	SEP	Bias	SEP(C)	RSQ
CP	0.91	0‡	0.93	0.94
NDF	2.6	−1.32	2.29	0.92
ADF	2.16	−0.86	2.03	0.73
IVTDMD	1.58	0.41	1.56	0.83

† ADF, acid detergent fiber; CP, crude protein; IVTDMD, in vitro true dry matter digestibility; NDF, neutral detergent fiber; RSQ, the coefficient of determination; SEP, standard error of performance; SEP(C), standard error of performance uncorrected for bias.
‡ Bias was set to 0 for the CP.

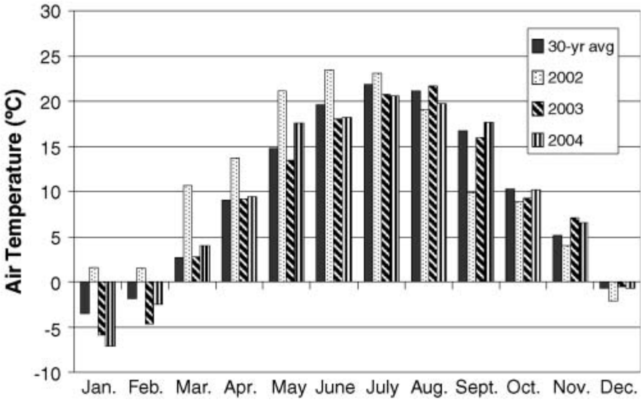

Fig. 1. Average monthly air temperature during 2002, 2003, and 2004 at the Haller Farm near State College, PA.

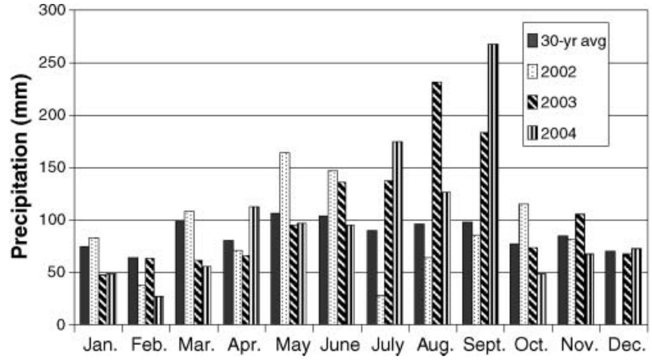

Fig. 2. Monthly precipitation during 2002, 2003, and 2004 at the Haller Farm near State College, PA.

random effect of replicates, and was analyzed as repeated across harvest sequence.

For each variable analyzed, year treatment was subjected to three covariance structures: unstructured, compound symmetry, and autoregressive order 1 covariance. The covariance that resulted in the smallest Akaike information criterion value was used (SAS Institute, 1999).

When significant ($P < 0.05$) effects due to species richness, mixtures, and years were detected, mean separation was conducted by the PDIFF procedure adjusted for the Tukey option in SAS (SAS Institute, 1999).

RESULTS AND DISCUSSION

Air temperature was above average during the 2002 growing season, near average in 2003, and below average in 2004 (Fig. 1). Rainfall during 2002 was above average in the spring and fall and below average during the summer (Fig. 2). Rainfall during the springs of 2003 and 2004 was near average, but well above average the remainder of those years.

Botanical Composition

Botanical composition data are presented as percentages based on total DM. There were significant changes in species composition between the first and last harvest within each species richness group (Table 4). Some of the species seemed to flourish under more intense population pressure (e.g., orchardgrass) and others under lesser levels (e.g., chicory).

The distinctive growth patterns for each species are shown in Fig. 3, 4, and 5. Many mixtures had a large proportion of weeds during spring of 2002 (Fig. 5). However, after the first harvest the proportion of weeds in all mixtures decreased. The red clover–chicory mixture was an exception, where by fall of 2003 weeds accounted for 19% of the botanical composition.

In general, the forage species tested in this trial can be placed into three groups. The first group, perennial ryegrass, red clover, and chicory, accounted for a large proportion of the DM during the first 2 yr, but were short lived. These declines are consistent with other published results. Declines in chicory after the second year in both mixtures and monoculture were reported by Belesky et al. (1999) and Sanderson et al. (2003). Belesky et al. (2002a) found that the proportion of red clover in grazed swards decreased after the first year of overseeding. Hoveland et al. (1986) found reductions in red clover stands by the second year and elimination by the third year.

The second group included alfalfa, birdsfoot trefoil, and Kentucky bluegrass, which decreased in their relative abundance by the end of the trial. Alfalfa decreased as a result of high grazing frequency. Birdsfoot trefoil and Kentucky bluegrass failed to compete with tall grasses and legumes under the conditions of this study and were present only in very small amounts.

Table 4. Contribution to botanical composition before the first grazing (initial) and before the last grazing (final) for all species in two-, three-, six-, and nine-species mixtures.

	Mixtures							
	2 species		3 species		6 species		9 species	
Species	Initial	Final	Initial	Final	Initial	Final	Initial	Final
	% of sward dry matter							
'Common' Kentucky bluegrass	18.5	19.9	19.1	4.6	0.8	0.3	0.0†	1.2
'Tekapo' orchardgrass	28.7	72.9	29.3	75.7	7.2	48.6	5.2	27.5
'Tonga' perennial ryegrass	92.8	40.5	82.6	35.9	74.1	17.9	43.9	23.4
'Bronson' tall fescue	37.0	87.8	25.7	87.3	8.5	19.4	2.7	14.9
'Winter' alfalfa	50.3	19.1	32.5	1.7	12.9	6.7	10.1	3.7
'Viking' birdsfoot trefoil	ND‡	ND	3.7	0.0	0.2	0.0	0.0†	0.0
'Starfire' red clover	51.0	27.0	54.7	4.2	17.4	10.9	13.8	10.4
'Jumbo' white clover	9.6	65.9	3.1	38.6	0.9	17.8	2.7	15.3
'Puna' chicory	18.1	7.3	14.3	7.2	10.0	0.1	6.5	0.6

† Present in <0.1% of botanical composition.
‡ ND, no data; BFT was not used in two-species mixtures.

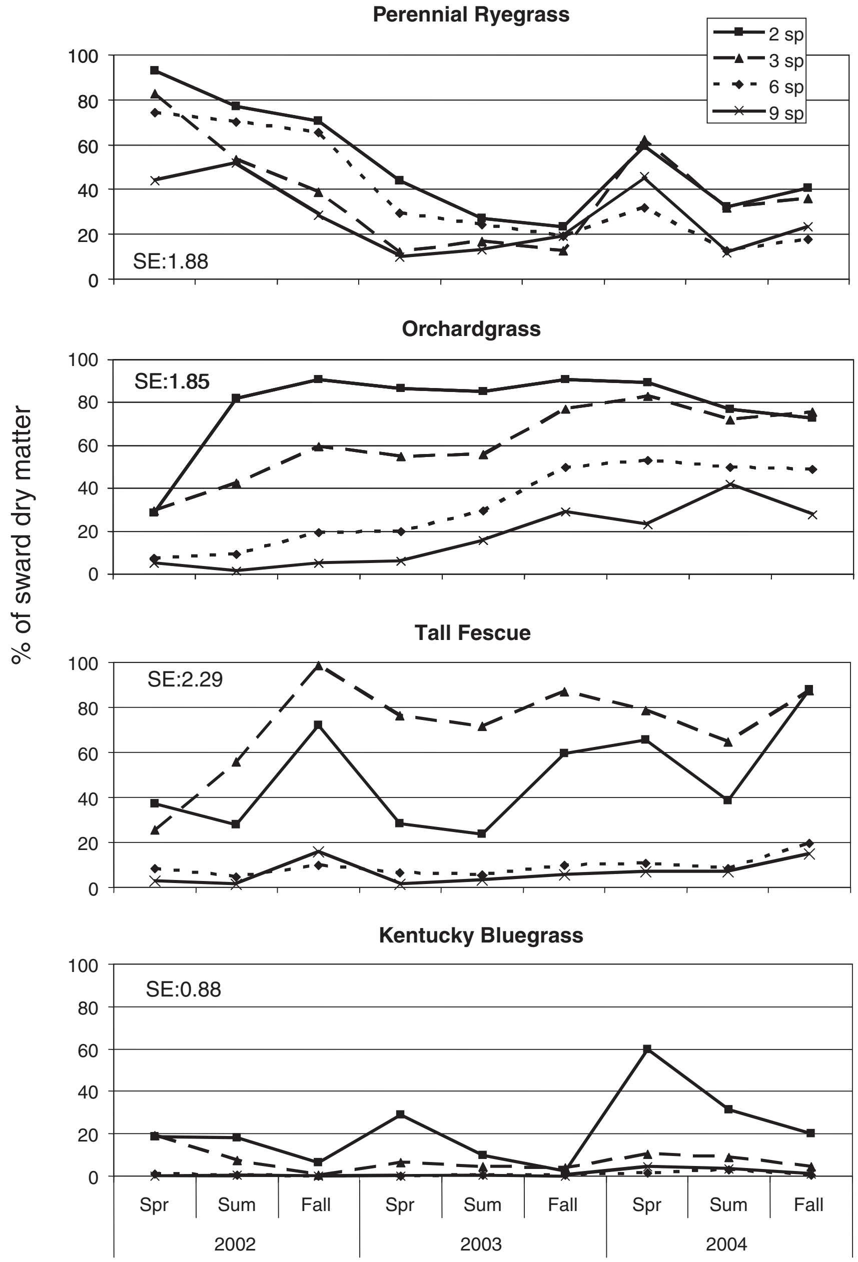

Fig. 3. Grass species botanical composition (expressed as a fraction of botanical composition of the stand) in two-, three-, six-, and nine-species mixtures during spring, summer, and fall of 2002, 2003, and 2004.

The third group included orchardgrass, tall fescue, and white clover. The first two were the dominant species in several mixtures at the end of the experiment (Table 4). White clover increased in abundance in 2003 and 2004, probably because of the higher rainfall in those years (Fig. 2).

Botanical composition is highly dynamic, influenced by the interaction of the particular components of the mixtures and the climatic conditions. Combinations of species in the first and third group are likely to be the most compatible either in simple or complex mixtures. The first group of species could be useful for a rapid establishment and DM production during the first year (Kessler and Suter, 2005), whereas the third group of species could add longevity and DM production for the subsequent years (Kessler and Suter, 2005).

Herbage Production

We found no significant mixture × year interaction for DM yield, so we pooled those data for yield analysis across years and then found significant ($P < 0.001$) differences among mixtures. A two-species mixture of red clover and tall fescue produced 10 400 kg ha^{-1}, which was the greatest yield (Table 5). The lowest yield, 7300 kg ha^{-1}, was produced by a mixture of white clover and Kentucky bluegrass. Differences in DM production among different alfalfa–grass mixtures

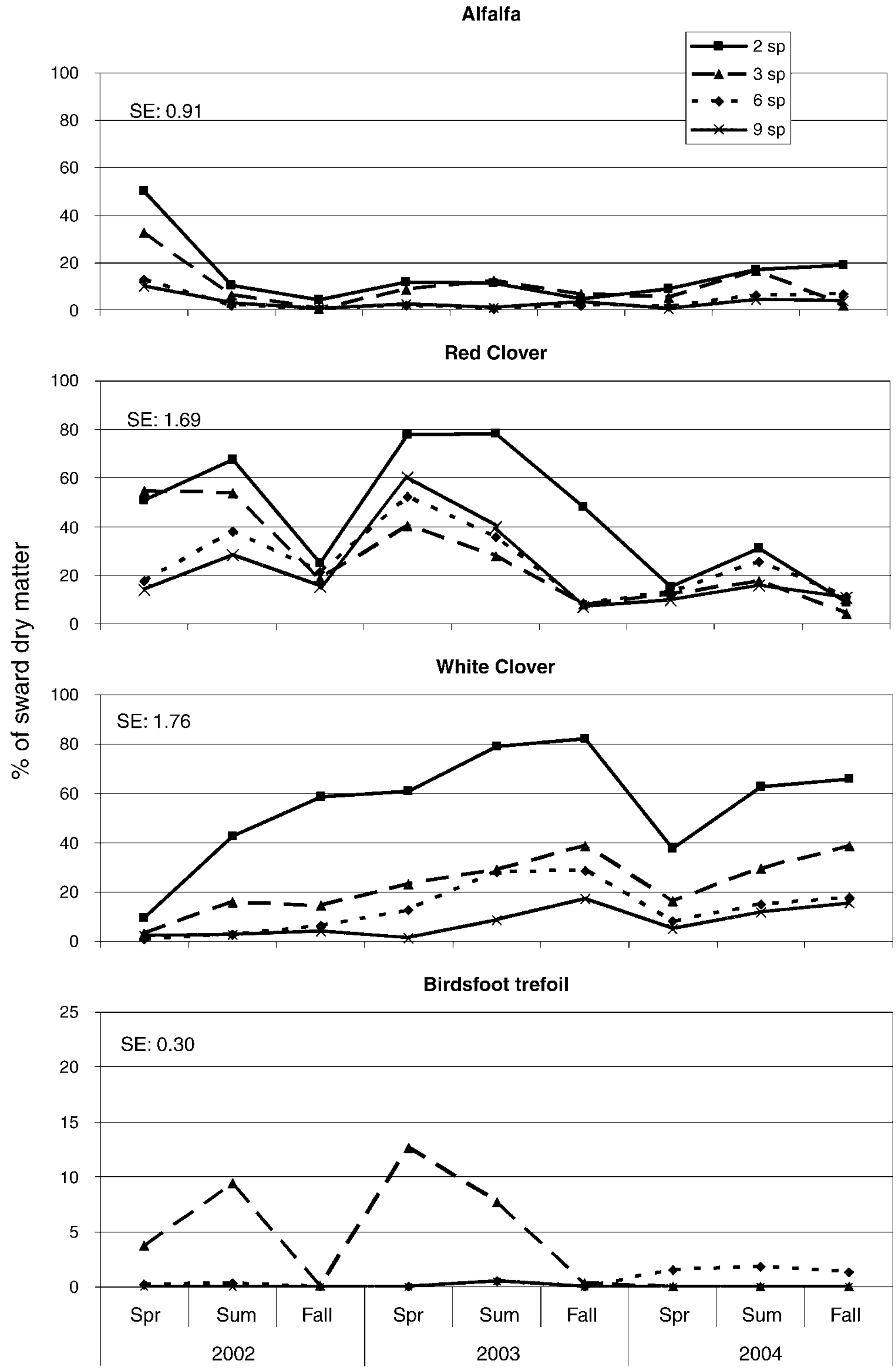

Fig. 4. Legume species botanical composition (expressed as a fraction of botanical composition of the stand) in two-, three-, six-, and nine-species mixtures during spring, summer, and fall of 2002, 2003, and 2004.

were also found by Chamblee and Lovvorn (1953) and among annual cereal–legume mixtures (Osman and Nersoyan, 1986).

On average, the six-species mixtures (9900 kg ha^{-1}) yielded more than the two-species mixtures (8700 kg ha^{-1}) and the three-species mixtures (8400 kg ha^{-1}). The nine-species mixture (9650 kg ha^{-1}) yielded more than the three-species mixtures, but not more than the two-species mixtures. Annicchiarico et al. (1995) also found that complex mixtures had no clear advantage over simple grass–legume mixtures. Thus, complex mixtures may also differ in their capacity to produce DM. The variation in DM yield within species richness groups decreased as mixture complexity increased (Table 5).

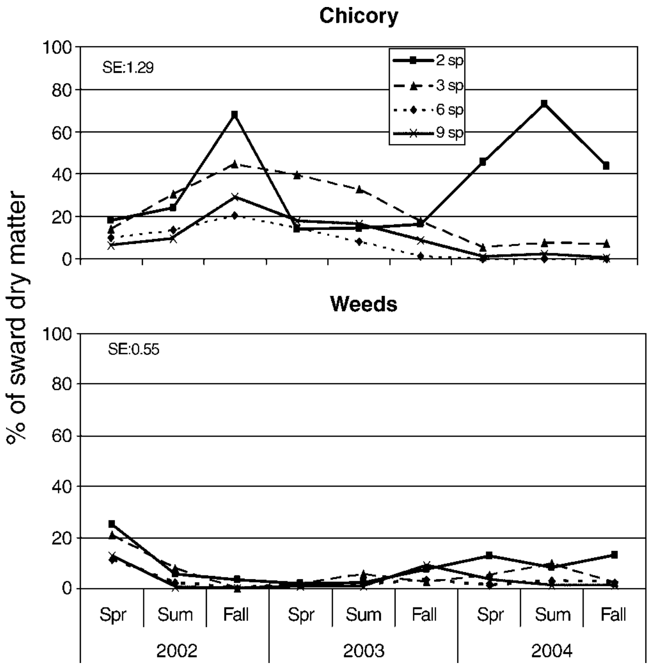

Fig. 5. Chicory and weed botanical composition (expressed as a fraction of botanical composition of the stand) in two-, three-, six-, and nine-species mixtures during spring, summer, and fall of 2002, 2003, and 2004.

This might be a result of an increase in the frequency of the dominant species (discussed in the previous section). Hence, the sampling effect (i.e., the increased chance of including one or more highly productive species in a mixture with increasing species richness of the mixture planted) appeared to be the driving mechanism for increased DM yield with increased species richness of the mixtures (Tilman, 2001). Therefore, the particular species that composed the mixtures were responsible for the DM production rather than the mixture complexity.

Table 5. Dry matter (DM) yield of the forage mixtures grazed at the Haller Farm near State College, PA. Data are the average of 2002, 2003, and 2004 growing seasons.

Mixtures	DM yield
	kg ha^{-1}
Two-species	
Orchardgrass–alfalfa	9300 bcde†
Kentucky bluegrass–white clover	7300 a
Tall fescue–red clover	10400 e
Perennial ryegrass–white clover	7900 abc
Chicory–red clover	8500 abcd
Three-species	
Orchardgrass–alfalfa–chicory	8300 abcd
Perennial ryegrass–white clover–chicory	7400 ab
Tall fescue–Kentucky bluegrass–birdsfoot trefoil	7900 abc
Orchardgrass–red clover–white clover	10100 de
Six-species	
Orchardgrass–tall fescue–Kentucky bluegrass–perennial ryegrass–red clover–white clover	10300 e
Orchardgrass–perennial ryegrass–Kentucky bluegrass–white clover–birdsfoot trefoil–chicory	9100 abcde
Orchardgrass–tall fescue–alfalfa–red clover–birdsfoot trefoil–chicory	10300 e
Nine-species	
Orchardgrass–tall fescue–perennial ryegrass–Kentucky bluegrass–alfalfa–red clover–white clover–birdsfoot trefoil–chicory	9700 cde
SEM	505

† Means followed by the same letter are not significantly different according to Tukey's mean separation ($P < 0.05$).

When expressed as percentage of total DM distribution during the growing season, the comparisons among species richness groups for spring and summer were not significant ($P < 0.73$ and $P < 0.76$ for spring and summer, respectively). During fall, the two-species mixtures had smaller percentage of total DM compared with the three-species mixtures. However, the more complex mixtures (six- and nine-species mixtures) were not different from either the two- or the three-species mixtures. These results disagree with Belesky et al. (2002b), who showed that mixtures of cool-season grasses, warm-season grasses, and legumes had a more even distribution of DM during the growing season.

Distribution of DM yield during the growing season was influenced more by the weather pattern than by the species richness of the mixtures (Fig. 6). In 2002, about 48% of the total DM was produced during spring and about 37% in summer. That year had a wet spring followed by a hot and dry summer. In 2003 and 2004, a higher proportion of the total DM was produced during summer (48% and 52% for 2003 and 2004, respectively) than in spring (36% and 39% for 2003 and 2004, respectively). Those years each had a cold spring followed by a wet and relatively cool summer.

Forage Nutritive Value

There were slight-to-nonexistent differences in nutritive value among the species richness groups (Table 6). These results contrast with White et al. (2004), who reported a negative relationship between forage species richness and CP and a positive relationship between NDF and forage species richness. This difference in their results may be due to the fact that the lower-species-rich sites were dominated by perennial ryegrass–white clover, and native species dominated the more diverse sites.

Legume proportion of the mixtures explained most ($r^2 = 0.85$) of the variation in CP concentration among all mixtures; the grass proportion explained most ($r^2 = 0.85$) of the variation in NDF concentration. This is consistent with Sheaffer et al. (1990) and Zemenchik

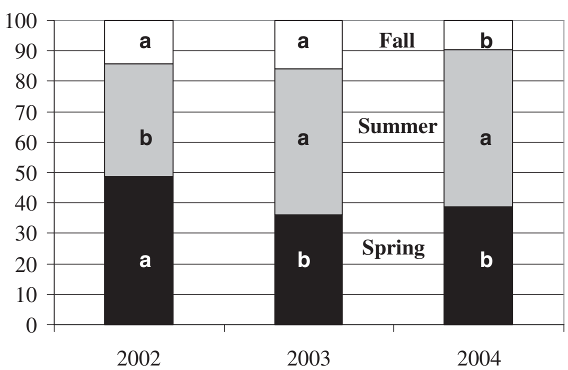

Fig. 6. Seasonal dry matter (DM) production (expressed as percentage of total DM) for 2002, 2003, and 2004. Shaded areas of each bar refer to forage growth during particular seasons (black, spring; gray, summer; white, fall). Yields within each season with same letters are not significantly different among years according to Tukey's mean separation ($P < 0.05$).

Table 6. Forage nutritive value influenced by species richness (number of species in the mixtures) under grazing at the Haller Farm near State College, PA. Neutral detergent fiber (NDF) and in vitro true dry matter digestibility (IVTDMD) data are averages of 2002 and 2003 growing seasons. Acid detergent fiber (ADF) and crude protein (CP) data were not averaged during the 2 yr due to species richness × year interaction.

Species richness	ADF 2002 Mean	ADF 2002 SEM	ADF 2003 Mean	ADF 2003 SEM	NDF 2002–2003 average Mean	NDF 2002–2003 average SEM	CP 2002 Mean	CP 2002 SEM	CP 2003 Mean	CP 2003 SEM	IVTDMD 2002–2003 average Mean	IVTDMD 2002–2003 average SEM
	g kg^{-1} DM											
2	257	3.8	244 a†	3.2	361 b	4.9	228 a	2.1	253 a	2.2	887	1.7
3	260	4.0	264 b	3.5	400 a	5.4	210 b	2.3	221 c	2.5	885	2.0
6	260	4.3	261 b	4.0	400 a	6.2	209 b	2.6	238 b	2.9	889	2.2
9	252	6.2	248 ab	6.6	363 b	10.3	216 ab	4.4	247 ab	5.0	894	3.7

† Within columns, means followed by the same letter are not significantly different according to Tukey's mean separation ($P < 0.05$).

et al. (2002), who reported that variation in CP was highly related to legume percentages and NDF-to-grass percentages in grass–legume mixtures. These results are consistent with the observations of Sleugh et al. (2000) and Belesky et al. (1999) in that shifts in botanical composition affect forage nutritive value. The impact of grass-to-legume proportion on nutritive value is independent of mixture complexity.

CONCLUSIONS

While perennial ryegrass, red clover, and chicory were the dominant species for a brief time in some mixtures at the beginning of the experiment, they were short lived. Orchardgrass, tall fescue, and white clover were the dominant species in several mixtures by the end of the study regardless of the initial number of species in that group. Low-growing species such as birdsfoot trefoil and Kentucky bluegrass did not compete well with taller grasses and legumes under our management conditions and environment, hence would not be advantageous to complex forage mixtures. Forage nutritive value was influenced more by the grass–legume proportion than by the mixture complexity. Finally, mixtures containing six species produced more herbage DM than the two- or three-species mixtures. However, herbage production varied within species richness groups. Thus, herbage production was influenced more by species composition than by mixture complexity. We conclude that species selection is more important than mixture complexity in achieving great yields and forage nutritive value with forage mixtures.

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